NASA CR-144826

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N77-13493

(NASA-CR-144826) LANDSAT D USER DATA PROCESSING STUDY Final Report (General Electric Co.) 57 p HC A04/MF A01 CSCL 05B

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G3/43 58214

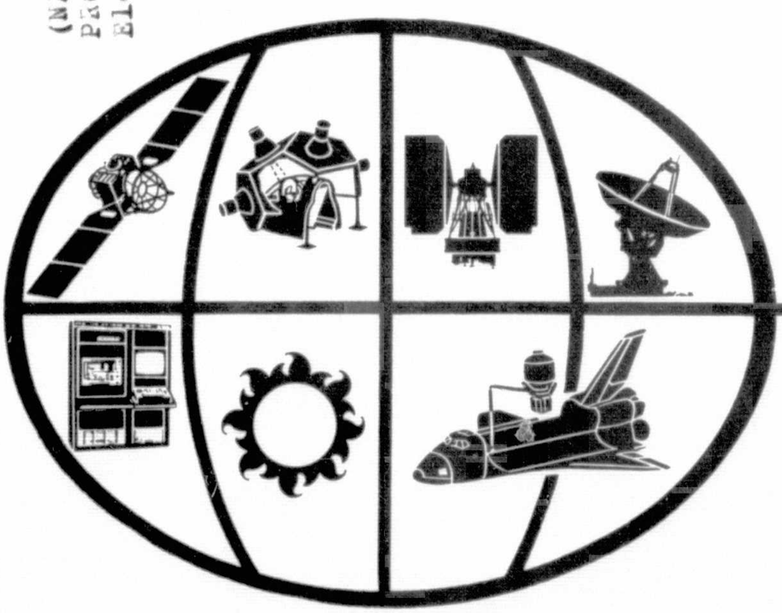
22 NOVEMBER 1976

LANDSAT D

USER DATA PROCESSING STUDY

FINAL REPORT

Prepared for
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771



space division

CONTRACT NO. NAS 5-23412, Mod 4
GE DOCUMENT NO. 76SDS4277

GENERAL ELECTRIC

This final report is submitted by the General Electric Space Division in partial satisfaction of the contractual requirements of Contract NAS 5-23412, Modification 4.

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INTRODUCTION AND SUMMARY

1.1 BACKGROUND

The pressing need to better survey and manage the earth's resources and environment has prompted man to explore the possibilities of remote sensing from space. Early efforts began with space photographs from the Gemini and Apollo programs and continued with multispectral data from Landsat 1 and 2 spacecraft. Landsat D is currently planned as the next major step for the Earth Resources Program.

Landsat 1, launched in 1972, marked the start of NASA's Earth Resources satellite program. This successful spacecraft was followed two and a half years later with Landsat 2, an identical spacecraft. The overwhelming success of these two Landsats, demonstrated through hundreds of experimental programs, has motivated NASA to continue to improve the Earth Resources satellite program. The third satellite, Landsat C, has been procured and is scheduled for launch in late 1977. This third satellite will carry a modified Multispectral Scanner and will utilize an improved digital ground system. NASA is now planning for the next step, Landsat D, which will provide several major advances. Landsat D will incorporate the Thematic Mapper (TM) as a new sensor, it will utilize the Multi-mission Modular Spacecraft (MMS), it will make use of the Tracking and Data Relay Satellite System (TDRSS) and it will employ a new more advanced ground system. Each of these represent significant improvements in the state-of-the-art. This study is one of several which address various aspects of the planned Landsat D system.

As the Earth Resources Program has matured through the Landsat spacecraft it has begun the transition from an experimental research activity to a sound demonstration of proven utility. This important transition will be completed with the Landsat D system which incorporates several key improvements over the current system. These improvements, based on experience with the existing Landsats, will provide new capabilities in the spacecraft, the sensor, the ground system, and the overall system design. These system

capabilities - which emphasize improved vegetation analysis, prompt availability of data, frequent coverage, and precise data registration and overlay for better change detection will permit the Landsat D to capture already proven economic benefits in such diverse applications as:

- Monitoring world-wide food productivity
- Mapping agricultural land use
- Monitoring rangelands
- Surveying forest resources
- Managing critical watersheds
- Detecting land use changes
- Oil/mineral exploration

An artist's concept of the Landsat D system is shown in Figure 1-1. The spacecraft will be based on NASA's new Multi-mission Modular Spacecraft (MMS) and will operate two remote sensing instruments: a Thematic Mapper (TM), with 30 meter ground resolution, and a Multispectral Scanner (MSS), with 80 meter resolution. The system provides two data communication paths to the Earth; one is a direct readout link for ground stations (both

Figure 1-1. Landsat D System

domestic and foreign) within range of the spacecraft, and the other is a relay link via the Tracking and Data Relay Satellite System (TDRSS) for nearly full global coverage. The spacecraft will be in a sun-synchronous orbit with a descending node time of 9:30 AM (similar to current Landsats). The orbital altitude and inclination will provide near global coverage of the land and near coastal regions with a repeat cycle every 16 to 18 days.

The use of the new MMS spacecraft as the basic bus will provide both improved sensor pointing accuracy (±0.01 degree) and stability (10^{-6} degrees/second). These improvements will manifest themselves in more accurate and more straightforward geometric corrections of the image data; both relative (image to image) and absolute (with respect to the Earth's surface). The MMS incorporates modular subsystems in the key areas of power, attitude control, and command and data handling. This modularity together with the compatibility for both conventional and Space Shuttle launches will enable in-orbit repair and refurbishment of the spacecraft.

The Thematic Mapper, TM, is an evolutionary improvement of the MSS and provides several significant capabilities. The spatial resolution on the ground has been reduced to 30 meters (compared to 80 for the MSS) which will allow radiances to be measured for areas (pixels) less than one sixth the size as for the MSS. The TM will incorporate six spectral bands (and have the capability for a seventh) which have been located primarily on the basis of their ability to discriminate vegetation (a fundamental application of remote sensing). In addition the radiometric sensitivity of the TM has been improved by reducing the signal-to-noise characteristic and increasing the levels of digital quantization. These sensor changes combine to cause the TM to have a data rate of 120 Mbps, (an order of magnitude increase over the 15 Mbps of the MSS).

For remotely sensed multispectral data to be truly practical for many potential operational users (agricultural analysts, hydrologists, etc.) it must be received by them in usuable form within 48 to 96 hours after imaging. Promptness in receiving data products is one of the most critical aspects of the Landsat System.

The Landsat D System will be thoroughly integrated with the needs of operational users. It will include improved preprocessing of all data, central data processing, archiving and retrieval,

low-cost receiving and data centers for large volume users (such as the U. S. Department of Agriculture) and provide maximum efficiency and economy in utilization by state, regional, and foreign users. Featuring the rapid electronic transmission of all data, the Landsat D system will reduce the time between satellite imaging and user reception of data to the required 48 to 96 hours.

As illustrated in the artist's concept the system provides two data links to the ground. The first link, for both MSS and Thematic Mapper data, is directly from the satellite to domestic and foreign ground stations as the satellite passes through their reception areas. The second link is via the Tracking and Data Relay Satellite System (TDRSS). As shown, the data is transmitted to a TDRSS satellite, in stationary orbit, and relayed to the TDRSS receiving station. The TDRSS receiving station transmits the data via a domestic communications satellite to a central data processing facility that, in turn, relays the data to any local data distribution center equipped to receive it. This link, via TDRSS and the communications satellite, will thus have global acquisition and relay capabilities, providing rapid access to Thematic Mapper data for users throughout the world. Both data links have a planned maximum data capability of 135 Mb/second at a 10^{-5} bit error rate.

The Landsat D system described is currently in the planning stages by NASA. As part of the planning for this future system, NASA has undertaken a series of studies, with General Electric and others, to investigate various system options. This particular study is one of seven conducted by General Electric to explore different aspects of the total ground system that will be required by Landsat D in order to meet the overall mission objectives.

The seven ground system studies are:

1. Local User Terminal Study - an investigation into the requirements and options available for direct readout (primarily foreign ground stations) of Landsat D data.

2. User Data Processing Study - an effort to estimate the scope, size, and cost of the major user data processing system requirements.

3. Data Processing Facility Study - a requirement and sizing study to provide preliminary estimates of the scope and cost of NASA's central Landsat D data processing center.

4. GSFC Research & Development Study - a survey and analysis of the functions and facility required of NASA to continue the basic research on spaceborne remote sensing and its applications.

5. Operation Control Study - an analysis of the modifications necessary to upgrade or modify the NASA Operations Control Center (OCC) for Landsat D.

6. Data Transmission and Dissemination Study - an investigation into the options and limitations of various data communication alternatives including centralization versus decentralization.

7. Position Determination and Correction Study - an analysis of the impact and alternatives afforded by the MMS spacecraft of Landsat D on image geometric correction.

1.2 THE LANDSAT D GROUND SYSTEM

A top-level functional diagram of the Landsat D ground system is presented in Figure 1-2. The five major subsystems included are the Data Input Subsystem (DIS), the Central Data Processing Facility (CDPF), the Product Generation and Dissemination Facility (PGDF), the Data Management Subsystem (DMS), and the Agriculture Utilization Subsystem (AUS). Each of these subsystems is briefly described below.

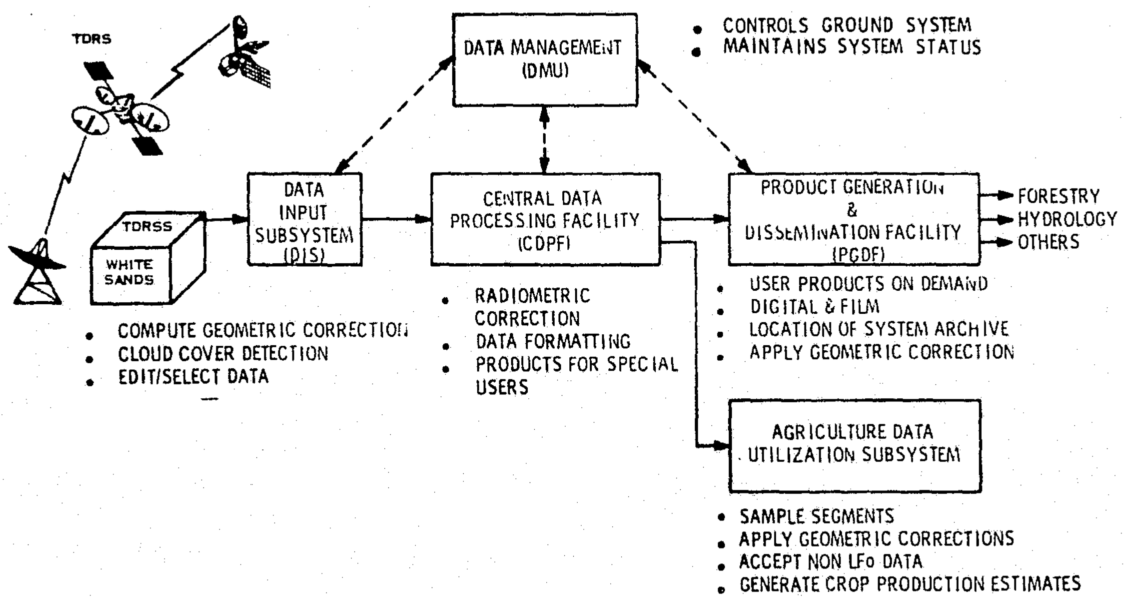

Figure 1-2. Ground System Concept

The Data Input Subsystem (DIS) receives 120-135 Mbps data from the TDRSS via dedicated cable interconnection. The prime functions of the DIS are to record the raw input data, to perform cloud cover detection and scene editing, and to compute geometric correction matrices on a per swath basis.

The Central Data Processing Facility (CDPF) receives edited data from the DIS and performs standard operations to all data. These operations include radiometric correction and data reformatting to a band-interleaved-by-line (BIL) format.

The Product Generation and Dissemination Facility (PGDF) is the main interface between the Landsat D ground system and general users. This facility provides Landsat D data, in either digital tape or film format, to users on demand. The data, which may be geometrically corrected to various map projection systems or enhanced as requested by the user, is available in a variety of sizes, formats, and media. The PGDF also houses and manages the system archive.

The Data Management Subsystem (DMS) provides the central point of control and data base management for the Landsat D ground system. Its prime functions include management of user demand, the system archive, system communications, and system redundancy. The DMS also maintains system status, production statistics, operations logs and administrative services.

The Agriculture Utilization Subsystem (AUS) receives data directly from the CDPF and performs those operations necessary to produce world crop production forecasts on a periodic basis. The operations to be performed include geometric correction, sample segment extraction, multispectral analysis, and areal and statistical analyses. It is included here as part of the ground system because it represents the first major user of Landsat D data.

Several other major subsystems included as part of the Landsat D ground system were considered. These include the Operations Control Center (OCC), the GSFC Research and Development Facility, and the Hydrologic Land-Use Utilization Subsystem. The OCC performs the functions required to plan, schedule, operate and evaluate spacecraft and payload

operations. The R&D facility enables NASA to perform research related to the Landsat program and its applications. The Hydrologic/Land Use Utilization Subsystem is similar in concept to the AUS and will generate land use maps over watershed areas within the US.

1.3 USER DATA PROCESSING STUDY SUMMARY

The Landsat D program is intended to satisfy a variety of missions, both experimental and operational, as well as to make data available to the public for individual applications and research studies.

The primary applications missions which are expected to be operationally served by the Landsat D are in Agriculture and Hydrology. Forestry and Mineral and Petroleum Exploration missions will be served as Application System Verification Tests, at least during early phases of the program, with later phase over to fully operational status.

Research, experimental, and private applications of the Landsat D data will be served by making data available to the public through the Product Generation and Dissemination Facility, and special arrangements may be made to supply data to foreign user agencies.

As part of NASA's planning exercise for the Landsat D program, it is necessary to understand the nature, requirements, and scope of these expected users. The purpose of this study is to investigate the major expected users of the Landsat D system and to perform a preliminary system design of their required facilities. This system design will then be costed in order to provide a ROM estimate of the incremental user costs necessitated by Landsat D.

One major use of these cost estimates is as part of an overall economic cost/benefit argument being developed by NASA for the Landsat D system. The implication of this motive is key; the system design (and corresponding cost estimates) must be a credible one, but not necessarily an optimum one. This study, therefore, produces reasonable design concepts and ROM costs but no attempt has been made to refine and optimize them beyond a "reasonableness" level.

1.3.1 AGRICULTURE MISSION

A series of experimental investigations, using multispectral and meteorological data to identify and measure the areal extent of major crop types and to estimate their yields, has established a base of technology, which if properly expanded, can satisfy the requirements of a major agricultural application objective i.e, crop production inventories over large areas.

Based on early experimental results, the U.S. Department of Agriculture (USDA) established a close working relationship with NASA for purposes of exploiting ERTS technology. As a result of this relationship, an application designated as the Large Area Crop Inventory Experiment (LACIE) was specified. Subsequently, a formal agreement was made between USDA, NASA, and the National Oceanic and Atmospheric Administration (NOAA), which delineates the responsibilities of each agency in conducting the joint multiagency experiment.

The LACIE project is designed to test a system which utilizes advanced remote sensing technology and computer processing of the data collected to provide up-to-date wheat production estimates required by various agencies within the USDA and by the public for effective decision making.

A general application objective shaping the overall LACIE design was to develop, test and prove an economically important application of remote sensing from space. The crop inventory application was chosen because it represented an economically important application which could feasibly be accomplished near term with a system built from existing technology. Wheat was chosen as the crop for the experiment because of its importance in human nutrition and international trade.

The operational agriculture mission addressed in this study will involve global periodic inventory of several major crops, providing monthly forecasts of crop production. The primary basis for this mission will be the techniques and technology currently being evaluated and demonstrated by the LACIE project.

The Agriculture Utilization Subsystem (AUS) of Landsat D will receive data directly from the CDPF in the same format as archival data. Geometric correction will be performed in the AUS, and sample segment subscenes will be selected for automated or interactive spectral analysis. This analysis will determine crop types and field areas for each crop observed in the sample segment, and by a statistical analysis a crop production forecast may be made. The product output of the AUS will be production forecast statistics to be used by the U. S. Department of Agriculture as management and policy making tools.

1.3.2 HYDROLOGIC LAND USE MAPPING

The Hydrologic Land Use Mapping application mission will consist of an interactive analysis terminal, similar to those in the Agriculture Utilization System, for the purpose of generating land use maps over watershed areas within the U.S. There are multiple users of these maps including:

- U.S. Army Corps of Engineers
- U.S. Department of Agriculture
- U.S. Forest Service
- U.S. Geological Survey
- State and Local Governmental Agencies

One primary function of these maps will be their use as inputs to hydrologic master runoff models. These models use indications of topography, rainfall, and soil imperviousness to simulate drainage basins.

1.3.3 OTHER APPLICATIONS MISSIONS

1.3.3.1 Forestry

For the forestry mission, Landsat D data will be used as the first stage of a multistage probabilistic sampling procedure for forest inventory purposes. The data will be supplied, on a routine basis, to the U.S. Forest Service from the PGDF. The geographic areas of interest for the forestry mission are all of the forested areas within the U.S.

1.3.3.2 Mineral and Petroleum Exploration

Landsat D data will be available, with a quarterly coverage cycle, of all areas of the world where mineral exploration may be conducted. This area will be supplied, on demand, to U. S. Government agencies and private mineral exploration and oil companies for their use in the location of areas of mineralization where further detailed exploration appears warranted.

1.3.3.3 Public Dissemination of Data

Landsat D data will be archived to permit public access to data products, on demand, for available global data. Such products will be supplied to private industry, to universities, and to local, state and federal government agencies for their own applications or R&D purposes.

Data which provides global coverage will be available on a quarterly basis. U.S. coverage will be available for all acquisitions every 16-18 days for 1 satellite or 9 days for 2 satellites .

The data products will be film images, either color or black and white, and digital data recorded on either Computer Compatible Tape (CCT) or High Density Tape (HDT). Radiometrically corrected data will be available with geometric corrections applied for different map projections or calculated but not applied.

1.3.3.4 Foreign Users

International agreements may be made whereby foreign governments may receive data on a routine basis. This data will be supplied from the PGDF in a manner similar to the general public dissemination of available data under the terms of any international agreements which may be made.

SECTION 2
MISSION DEFINITION

2.1 AGRICULTURE MISSION

The U.S. Department of Agriculture has been identified as a principal user of Landsat D data. The agriculture mission is to perform continuing and regular worldwide crop inventory. The processing throughput requirement is nominally one day (not to exceed 8 days) from acquisition for a 2-satellite configuration or 14 days from acquisition (max.) for a 1-satellite configuration. The crops to be surveyed can vary; a representative set of crops and a functional flow diagram of the system are identified in Figure 2-1. The crops are wheat (spring and winter), corn, soybeans, rice, potatoes, sugar cane and beets and small grains which include barley, oats and rye. These and other crops were investigated in terms of crop tonnage and crop value for world wide production. The selection criteria identified are the importance to U.S. Agriculture, the importance to world trade or U.S. trade, the information gatherable by remote sensing, the information not adequately gathered by current systems and the importance as a world food source. The tentative USDA priority recommendations are shown.

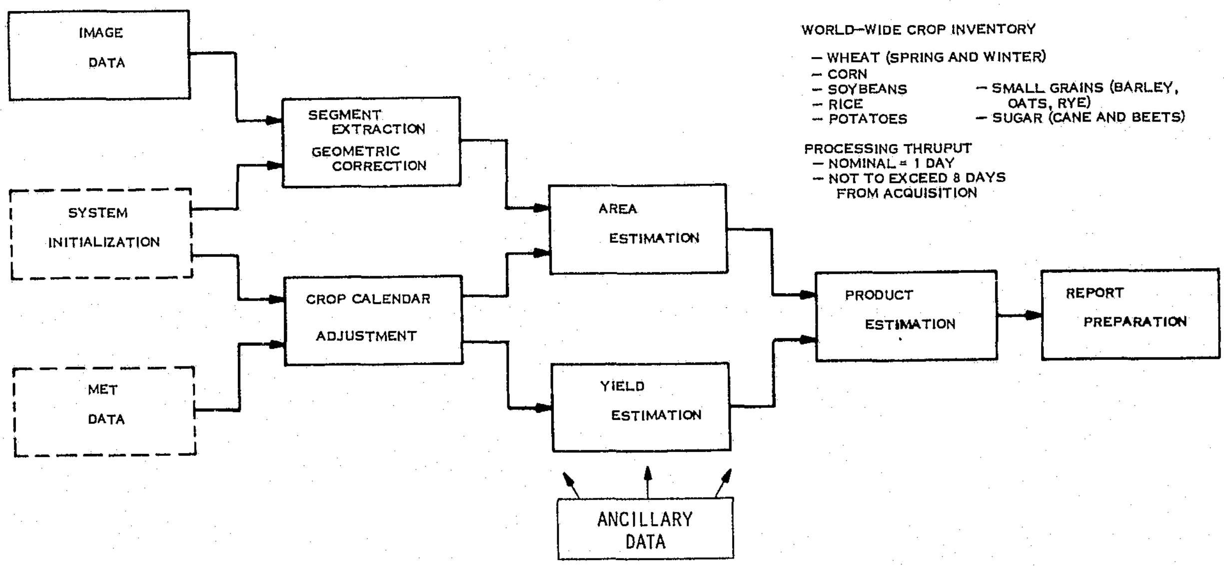

Figure 2-1. Agricultural Mission

2.1.1 GEOGRAPHIC COVERAGE AND DATA VOLUME

Analysis of world crop distribution maps indicates that for the sample crops, a peak monthly requirement of 4050 scenes is identified. When consideration is given to the need for 90% or less cloud cover, the number of scenes actually received by the AUS from the CDPF of Landsat D is 318 scenes/day (2-satellite system) for system sizing purposes.

The present LACIE system uses an average of three and a half 5 x 6 nautical mile sample segments per (185 x 185 km) scene for inventorying wheat only (in the United States). A multiplicative factor of 4 was used on this number to account for the multiple crops being inventoried; that is, 14 sample segments per scene average for the global operational Landsat system for all 6 crops. This would allow modifications to the present sampling strategy, would accept episodal events and anomaly conditions and would still represent a conservative estimate of the Agricultural Mission throughput requirement.

2.1.2 SYSTEM INITIALIZATION

System initialization is the a priori establishment of mission parameters and includes the following:

- Selection of countries and crops to be inventoried.
- The sampling strategy to be used, that is, sample size, allocation of samples within the scenes, and the selection procedure to be used in identifying the sampled segments.
- Scheduling - Preliminary identification of the scenes to be acquired and the priority for processing.
- Geographic Partitioning - Based on agricultural, climatic, and topographic factors; once established, partitioning is essentially fixed for years. Factors being equal, a given crop anywhere within a partitioned area could be expected to perform normally. Practically, the crop will vary due to other factors such as meteorology; thus, at any instant during the mission, the partitioned areas will be further stratified by meteorology isolines.

2.1.3 ANCILLARY DATA

Ancillary data is a collective term for the information which the agricultural scientist and analyst will accumulate to aid them in the every day performance of their several tasks.

Thus, ancillary data may include such diverse information as attache reports, USDA reports, foreign periodicals, photographs or even informal information on changes in cropping practices in a given region. It can be used wherever applicable in this system, for example, in augmenting meteorological data or in modifying yield estimates for a given region.

2.1.4 METEOROLOGICAL DATA

The source of meteorological data for the program is the National Meteorological Center (NOAA). It is collected by the world meteorological organization from more than 5000 sites throughout the world. It is input to the agricultural mission every three hours. The data elements of principal concern to the agricultural mission, are temperature (min. and max.) and precipitation. Unfortunately, the system is not yet perfect. Incomplete and missing information often characterizes the input and must be augmented by other means such as weather satellite photographs, extrapolation from surrounding regions or the use of historical data. For this and other purposes, the agricultural system will maintain a historical file of past years of meteorological information.

2.1.5 CROP CALENDAR ADJUSTMENT

Nominal crop calendars are available based on geographic partitions which identify the current nominal crop biophase estimated from historical data including crop planting and estimated harvest dates. The crop calendar will be adjusted daily using a software model resident in the master scheduling computer of the agricultural system. Adjustments are made based on the parameters of temperature and precipitation; that is, current meteorological data. The outputs are meteorological isolines which, as mentioned previously, will act to stratify the partitioned areas. The crop calendar is used to determine the segment extractive timing; that is, to identify and develop the schedules for use in specifying the scenes to be taken and the sample segments within the scenes. It is also used as ancillary information to assist in classification during interactive processing.

2.1.6 YIELD ESTIMATION

Crop yield is estimated by partition area, and, if necessary, by isoline stratification within a partitioned area. One approach to yield estimation uses a software regression model based

on historical information. It includes three factors: historical norm which may be likened to a constant offset; trend or slope superimposed on this based on factors such as plant breeding, mechanization used, fertilization practices, irrigation, etc; and a more variable component superimposed on the trend, which is the current meteorological data. Thus, the parameters which are input to the yield estimation model are the adjusted crop calendar and the current meteorological data of temperature and precipitation.

2.1.7 REPORT PREPARATION

Crop production (bushels or tons) equals area times yield and it is determined on a sample segment basis. The sample segments are then aggregated by zone, region and country and analyzed for statistical information. The production estimates are validated and evaluated by comparison with other sources and a detailed accuracy assessment is made.

Reports involving production are then generated for various agencies within the USDA such as the Foreign Agricultural Service (FAS), the Economic Research Service (ERS), and the Agricultural Stabilization and Conservation Service (ASCS). These are by crop and by country. Reports are prepared periodically as required of the USDA by law. A historical file of production results will be developed and maintained in the system for at least 10 consecutive years. Special reports will also be released covering anomaly analyses, episodal events and non-periodic or special purpose format studies performed by the system. Processing statistics will be gathered for use in evaluating system and personnel or individual performance. Typical elements to be examined are scene and segment throughput rates and automated vs. interactive processing ratios. These will be looked at in terms of countries analyzed, crops, the analyst doing the job, and the accuracy of the resulting data.

2.2 THE HYDROLOGIC LAND-USE MISSION

Water resources systems planning, design and management is an important activity in many levels of government. Planning of waterworks and flood control structures, from municipal storm sewers to dam reservoir systems, requires knowledge of such parameters as average and peak flow rates and storm runoff volumes. River basins are studied to survey water supply and quality, erosion, sedimentation, flooding and irrigation. These parameters, in turn, can be derived from the watershed models developed by the various federal, regional

and local agencies. A primary input for these studies in addition to hydrologic and meteorologic information is land use and land cover data; it is the function of the Landsat D Hydrologic Land-Use mission to provide this data.

Water resources information users can be classed into two groups: the Federal agencies and the regional-local agencies. Federal agencies are involved in a myriad of projects ranging from studying whole river basins covering thousands of square miles to small stream watersheds affecting only a few acres. However, because of their centralized structure, their land use and land cover data requirements can be served by a single, large efficient data processing facility.

However, the regional and local users, even though they may be involved in projects affecting large areas, tend to be diverse and scattered and differ greatly in their data needs. Although they will benefit from a central processing facility, they will most often utilize raw data which they process themselves to their unique requirements or they will obtain highly refined data already prepared by a federal agency, such as USGS topographic maps.

Due to these considerations, the Hydrologic Land-Use Mission is structured primarily to meet the needs of the Federal Agencies and was initially sized to meet their estimated requirements. However, the system has been given sufficient margin such that it can be used by the regional and local agencies. The system is also designed with sufficient flexibility and modularity that, as its capabilities become more well known and appreciated, it can be efficiently expanded even further.

2.2.1 MISSION REQUIREMENTS

In order to design the Hydrologic Land-Use data processing system, it is first necessary to determine the number of Landsat images that the facility must process per year and at what speed or throughput rate they must be processed. Several approaches were considered. First, in conversation with water resources specialists, it was estimated that at present 500,000 square miles of watersheds were under study by the major federal agencies during one year and that by the 1980's this would increase to 1,000,000 square miles. Since these studies often require temporal data, this amounts to some 200 to 300 images per year.

A second estimate was that all of the basic watersheld areas in the U. S. would be at least looked at by hydrologists every five years and that by the 1980's the entire U. S. would be covered every three years. This requires approximately 500 images per year.

Realistically, it is likely that each of the major agencies requiring land use data, though their areas overlap, will want imagery at different times and with different sun angles. Therefore, a better approach is to consider the major agencies' data needs separately and sum the numbers of images required.

The major hydrologic projects of four agencies were reviewed and a conservative estimate of imagery requirements was made.. The U. S. Department of Agriculture, for example, performs a large number of surveys of small watersheds every year. Typically, these watersheds measure in the range of five square miles. Although it is likely that one Landsat image of 10, 000 square nautical miles would include more than one of these watersheds, it was assumed that one image per watershed would be acquired and processed. Further, it was assumed that to obtain adequate land cover type differentiation, two images taken at different times of the year would be desirable. The same conservative approach was applied to each of the other missions resulting in a total basic requirement of 1774 scenes* per year. The imagery requirements of these missions are tabulated in Table 2-1.

*2 times per year

Table 2-1. Mission Requirements

TASK	AGENCY	AVERAGE AREA (MI^2)	NUMBER OF TIMES/YEAR	NUMBER OF LFo SCENES
SITE SURVEY	COE	30000	5	30
WATERSHED MAPPING	COE	100	75	75
AGRICULTURAL WATERSHED	USDA	5	750	750
MAJOR BASIN SURVEY	USDA	30000	1	6
WATERSHED SURVEY	USGS	10000	2-3	6
WET LAND SURVEY	USGS	15000	1	5
FOREST WATER INVENTORY	USFS	10000	1	15
				887

- FOR TEMPORAL COVERAGE:
  887 x 2 = 1774 SCENES PER YEAR

2.2.1.1 System Inputs

Inputs to the Hydrologic Land Use system will be Landsat data plus ancillary data. Because the throughput rate for the system need be no faster than six months, standing orders for imagery will be placed at the PGDF (Product Generation and Dissemination Facility). Upon receipt, the imagery will be inspected to determine that the quality is high, that cloud cover is not over the area of interest and that the scene actually includes the area of interest. After passing these tests, digital tapes of the scenes will be ordered and all processing will be performed digitally.

To supplement the Landsat data, ground truth information will be required so that detailed extractive processing can be performed. In addition, information such as soil characteristics, topographic slopes, erosion indices, land use weighting factors, and watershed boundaries is needed for further processing, in order to produce results more useful to the user agencies. This information will, in large part, be furnished initially by the user in the form of maps or tabulations. Once obtained, however, it will be archived in the central facility so that it is available to all users.

2.2.1.2 System Outputs

Planned outputs for the system will be at two levels of processing. The first level will be the data classified by land use/land cover types. This level of classification can be accomplished using the Landsat imagery merged with a minimum of ground truth and will form the final output product for many of the projects. The second level of processing is obtained by merging the land use classified data with some or all of the ancillary inputs discussed above. This merge results in refined products such as maps of relative imperviousness, which can form a final product or, in digital form, can be the input to computerized hydrologic models directly.

The physical form of the outputs will take many shapes, independent of the level of classification. Map overlays in both color and alphanumeric format at many different scales will be a primary output product. Overlays displaying individual classes and composite classes will both be required. Statistical tabulation of such parameters as area/class, area vs. percent imperviousness, etc., will also be required.

A film recorder will be available for production of imagery. In addition, digital tapes of the extracted data which can act as inputs to computer models will be available.

2.2.2 SYSTEM OPERATION

A functional flow diagram of the hydrologic land use processing system is contained in Figure 2-2. As has been noted, Landsat D imagery is obtained on a standing order basis from the Product Generation and Dissemination Facility (PGDF). This standing order will be keyed to the 1/16 scene sector cloud cover estimates being produced by the Data Input Subsystem of Landsat D and cataloged for user access. If the desired sectors contain a significant amount of cloud cover, the standing order will not be filled. A standing order file will be maintained in the system data base, will be updated as appropriate, and will be forwarded to the PGDF on a weekly basis.

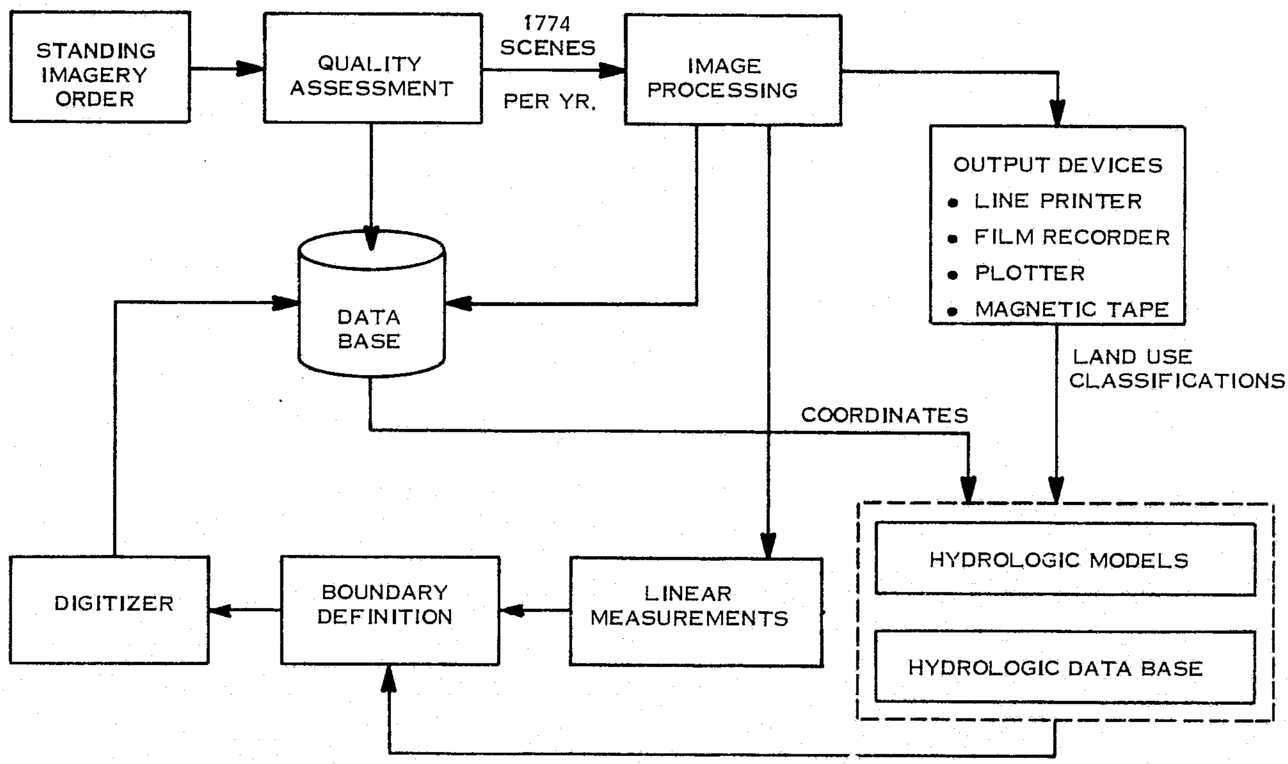

Figure 2-2. Hydrological Land Use Functional Flow

On receipt of an image from the PGDF (initially in a film format), a visual inspection will be performed to insure that the image is of the correct area and that the particular area of interest in the scene is sufficiently cloud free. If an image passes these requirements, an order for a high density digital tape copy of the scene will be entered into the data base and forwarded on to the PGDF. The requested digital tape will likely be corrected to a Universal Transverse Mercator (UTM) map projection grid so its subsequent products may be fitted to the USGS topographic maps.

Image data can take four distinct paths through the system. The first path is the case when an image of a specific area enters the processing center for the first time. Multispectral classification of the area of interest is performed in the interactive processor, using the disk as on-line storage, in order to obtain the desired themes. The precise boundary of the watershed or area of interest will have previously been delineated on a topographic map or other suitable base. This boundary will have been digitized and the X-Y co-ordinates of the boundary entered into the data base. Following the classification step, this boundary will be "anded" with the extracted themes such that the output data will be of precisely the desired area. At this point the output data (themes) will be put onto tape and subsequently processed through any of the output devices. It is expected that processing statistics and map overlays will be the nominal output from this processing step. The specific spectral signatures resulting from this analysis will be entered into the data base for possible later use.

The second pass through the system will occur when an area is being reexamined after some period of time, such as 3-5 years, has passed. In this case, the analysis will proceed through the classification phase as in path one, perhaps making use of the previously derived spectral signatures. A subsequent step, change detection, will then be performed. Using the archived categorized tape from the previous analysis, additional categories of land use that have changed will be created. Output from this analysis may be existing land use as a base with areas of change as highlights. All of the output options are then available as in path one.

The third path through the system involves updating physiographic data in the hydrologic data base. Parameters such as stream length, river basin extent, impounded water bodies,

etc., may be inaccurate on topographic maps or as given. Following a multispectral analysis, these physiographic parameters may be identified, delineated, and transferred to the topographic base maps.

The final path through the system will make use of previously developed hydrologic models. These hydrologic models will be run either externally, on a computer system supplied by the user agency, or on the mini-computer located in the interactive processor; however, no additional cost for this software development has been included in this study. Using digital tapes resulting from the spectral analysis and supplementary physiographic data which may have been digitized from topographic maps, hydrologic-land-use processed data such as maps of imperviousness or runoff potential may be constructed and output to the various peripheral devices.

2.3 OTHER APPLICATIONS MISSIONS

Besides the agricultural mission and the hydrologic land use mission, several other operational Landsat D missions have been considered. These are the Mineral and Petroleum Exploration Mission, the Forest Inventory & Monitoring Mission and the General Service Mission. There was no explicit study of the additional ground processing required for these missions since the economic benefits of each accrue from the availability of data at the Product Generation and Dissemination Facility.

2.3.1 THE MINERAL AND PETROLEUM EXPLORATION MISSION

The mineral and petroleum exploration industries currently make extensive use of Landsat data in the reconnaissance stage of their exploration efforts. It is an excellent tool for providing a geologic overview for undeveloped areas and has been shown to be extremely valuable even in geologically "well-known" areas.

The majority of the work performed to date has employed various methods of spatial processing and interpretation. This has involved the application of classical photogeology to Landsat data, searching for lineaments and other surface indicators of subsurface conditions. Recently, however, there has been a resurgence of interest in the use of spectral information in this area. Using principles from the field of geobotany, exploration engineers are now employing the latest techniques in multispectral processing.

The information extraction phase of this process is being performed and financed almost entirely by private companies. As one would expect, the results of such analyses are then classified company proprietary and are not made available to outside interests.

Due to the nature of the operational use of Landsat data in this field, no extractive ground processing subsystem was explicitly designed or costed in this study. It has been shown that the economic benefits of Landsat D data in the minerals and petroleum area accrue at the point that the data becomes available to private enterprise.

2.3.2 THE FOREST INVENTORY AND MONITORING MISSION

The Forest Inventory and Monitoring Mission is defined as those processes necessary to inventory and monitor U.S. commercial forests. This mission involves multi-sensor data collection and extensive ground processing.

Satellite remote sensing is used in the first portion of a multistage hierarchical sampling plan. This initial stage involves partitioning the data into broad classes of homogenous species. Later stages then attempt to classify specific areas as to their individual species and plant health.

The economic benefits resulting from the inclusion of Landsat D data in this inventorying and monitoring process have been computed on a net basis from the point at which the satellite data is made available to the various federal, state and local users. This point is the output of the Product Generation and Dissemination Facility in this system. Therefore, no design or cost is associated with the user processing function in this system study.

2.3.3 THE GENERAL SERVICE MISSION

The General Service Mission involves providing for the availability of Landsat D data to the general public on either a standing order or on a demand basis. This allows for the continuation of fundamental research in both academia and the private sector and provides products and support for small users.

The coverage defined for the General Service Mission is the landmass of the Earth from 60^{o}S to 70^{o}N on a once per quarter (90 days) basis. In addition, the U.S. landmass is acquired every time that it is available with less than 90% cloud cover.

All economic benefits for the General Service mission have been assumed to accrue at the point that data is made available from the Product Generation and Dissemination Facility. Therefore, in this case also, no further costs of user processing were addressed in this study.

SECTION 3

HARDWARE IMPLEMENTATION

3.1 AGRICULTURE UTILIZATION SYSTEM (AUS)

The Agriculture Utilization System equipment configuration is shown in Figure 3-1. There are three major equipment subsystems. Each has a central data computer and associated software. The three subsystems may be identified as: (1) extraction/correction, (2) schedule and system control, and (3) station terminals (a total of 16 terminals for the full up system).

3.1.1 SAMPLE SEGMENT EXTRACTION/CORRECTION

The functions associated with segment extraction are shown in Figure 3-2. For functional clarity, other functions actually part of the system scheduling subsystem, are included. It is assumed that system initialization has taken place; that is, the sample segments to be processed have been identified. It is further assumed that the scheduling function, that is, the identifying of the images to be processed, has also taken place prior to the start of this function.

Image data is received from the NASA Central Data Processing Facility (CDPF) on high density digital tape. Images are played back on a high density digital tape recorder and the data is decommutated in a programmable decommutator under control of the subsystem computer. Sample segments are extracted for the areas of interest. While the actual sample segment of interest is 309 x 370 pixels (5 x 6 nautical miles) at the resolution of Landsat D, the sample actually extracted will be 512 x 512 pixels or a full display CRT size to aid the operator in orienting himself relative to the sample segments of interest. Sample segments are geometrically corrected using the geometric correction matrix included on the tape header. Initial system requirements indicate that this will give adequate geometric accuracy between subsequent images of the same area. If the requirement should become tighter, the system is amiable to more precise, subpixel, geometric correction. The corrected samples are distributed to the appropriate terminals for analysis.

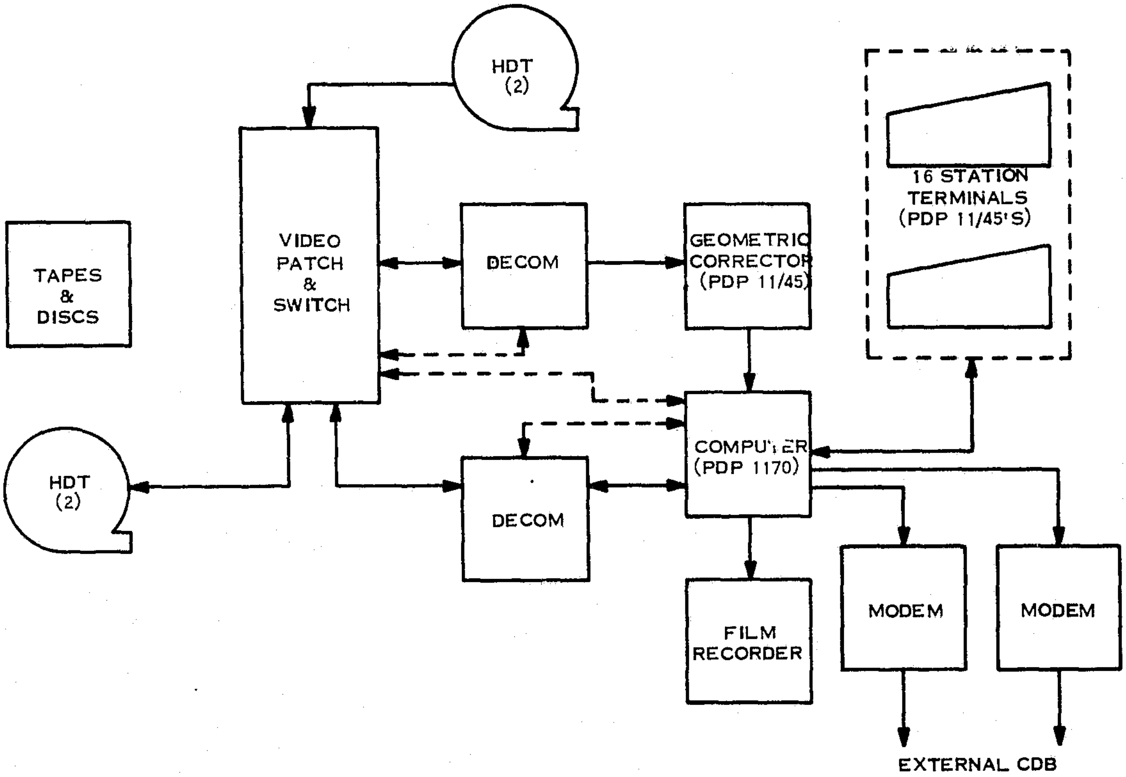

Figure 3-1. Agricultural Mission Equipment Configuration

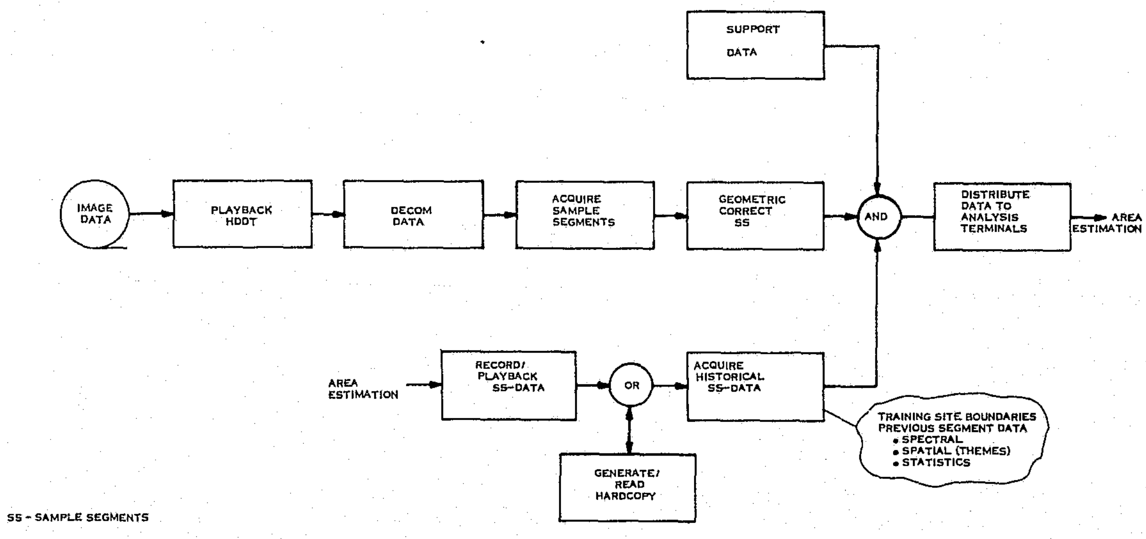

Figure 3-2. Segment Extraction Functional Flow

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Additional data required for subsystem sample segment analysis includes support data and historical data. Storage and access of historical data is a function of the schedule and system control subsystem and will be discussed below. For a given analysis, it will typically include:

- o The previous years imagery: sample segments, thematic information, scene statistics.
- o The last 10 + years of meterological data.
- o Ten + years of historical data: acreage, yield, production.
- o Training site boundaries

Training site boundaries represent those fields within the sample segment which have been previously selected as control. These fields are "known" to contain the crop under investigation. Determination of fields is part of the annual systems initialization and may be based on historical information, early imagery of the given fields and the experience and knowledge of the agricultural expert, together with other sources of information about the cropping practices for that area.

Support data is a general term to include all other sources of information available to the operator and used by him in performing his analysis. This would include partitioned areas and meteorological isolines within areas, yield models for this stratum, ancillary data previously discussed, and perhaps information requested from the Central Agricultural Data Base (e.g. Washington USDA).

Major equipment terms comprising the extraction/correction subsystem are shown in Figure 3-3.

3.1.1.1 Extraction Subsystem

Fourteen channel high density digital image tapes are played into the system and decommutated to acquire the geometric correction matrix and the sample segments. Transport and program decommutation, identified for the baseline system, are of the same types used in

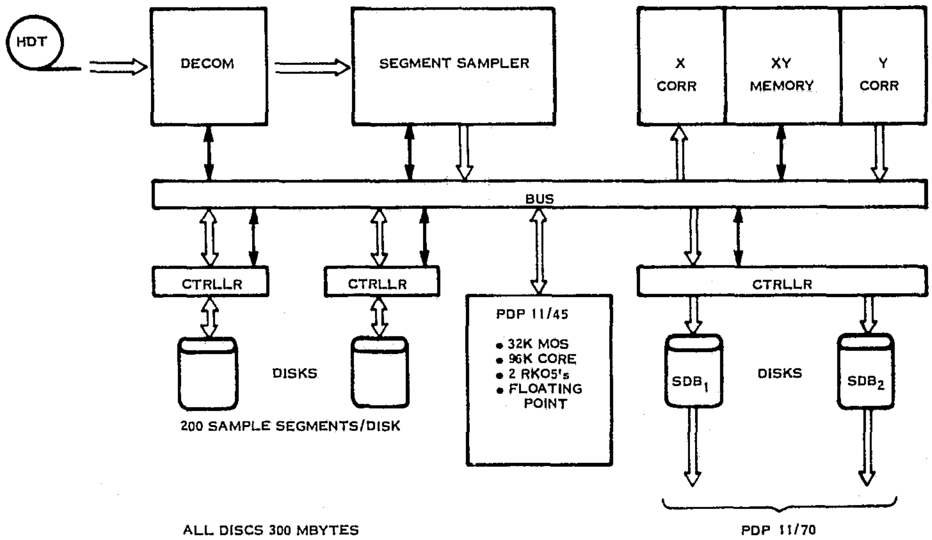

Figure 3-3. Extraction/Correction Processor Subsystem

other portions of the ground system. The correction matrix is transferred to the PDP 11/45* computer. The sample segments are buffered and transferred via the computer bus to one of two discs. Nominal playback speed is 20 megabits per second. A sample segment representing 512 of the 6170 pixels in a line represents an effective input rate of 1.2 megabits per second per sample segment. The 300 megabyte disc has a maximum input rate of 9.12 megabits per second. This represents a maximum input capability of 6 sample segments; that is, an image scanline can intersect up to 6 sample segments and still permit input at the 20 megabits per second tape playback rate.

With the assumed average of 14 sample segments per scene, some overlap of sample segments on a scanline is inevitable. Use of maximum rates in the above calculation, of course, implies that data will be mixed going into disc. To minimize mixing, several alternatives are available. First, two disc units are identified; thus, if only two sample segments are intersected by a scanline, data input can be altered between the two discs. If more than two sample segments are intersected, the tape recorder can be slowed down to decrease the input rate and permit separation of sample segments to the disc. Each 300 megabyte disc can store 200 sample segments.

* Throughout this report use is often made of specific equipment types and models - this should be interpreted as an indication of the level of required capability, not an absolute requirement for that particular equipment.

3.1.1.2 Geometric Correction Subsystem

Geometric correction within the Agriculture Utilization Subsystem is similar to that used in the NASA Product Generation Dissemination Facility (PGDF); that is, correction without scene rotation to align sampling lines with latitude lines. However, since the sampling area linear dimension (512 pixels) is only approximately 1/12 of an input line, the processing logic is considerably simpler. The geometric correction is done in two steps, first X correction and then Y correction. The same logic is used for both steps with the data being buffered in an XY memory between the X and the Y corrections. The baseline system XY memory is solid state and of the same type used in the terminals, as discussed below. An acceptable alternative would be to return the data to one of the two disc memories for temporary storage prior to Y correction.

Episodal event processing requiring full scene correction capability has certain application advantages; thus, one option to the baseline would employ the same geometric correction logic as used in the Product Generation Dissemination Facility. While representing more equipment for the agricultural system, this would be partially offset by the lower design cost (having already been designed for PGDF). In either case, the correction is controlled from the subsystem computer using the previously acquired correction matrix, or applicable portions thereof.

Data output from the Y corrector (geometrically corrected) is transferred to the segment data base memories, 300 megabyte discs. Two discs are used to permit "ping-pong" storage, to provide redundancy at this critical transfer point in the system, and to permit removal of discs for temporary archive of segment data.

Software modules which comprise the subsystem software would include input controller, format controller, decommutater controller, correction controller, output controller and diagnostics, with overall management by a control executive . All would run under the RSX11M or equivalent operating system.

3.1.2 SCHEDULE AND CONTROL SUBSYSTEM

The major equipment items in the Schedule and Control Subsystem are shown in Figure 3-4.

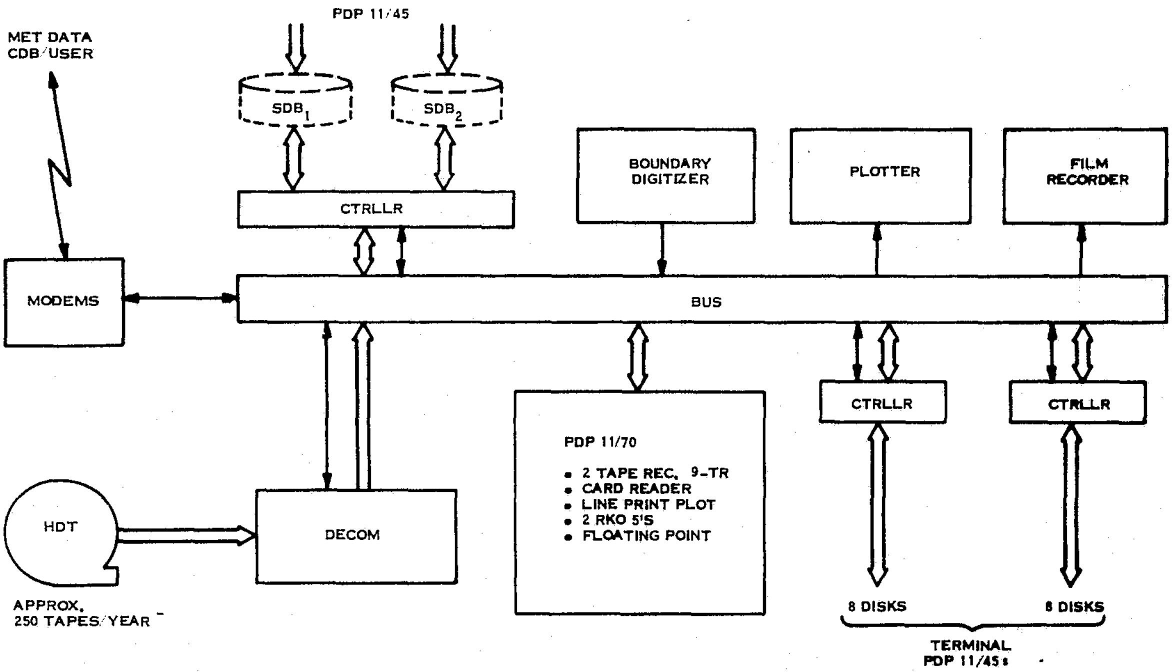

Figure 3-4. Schedule and Control Subsystem

The candidate computer is a PDP 11/70 with the following peripheral equipment:

- 2 tape recorders, 9 track
- 1 card reader
- 1 line printer plotter
- 2 RKO 5 discs
- floating point

The schedule and control subsystem and the extraction/correction subsystem share access to the two segment data base disc memories. The discs are used to accumulate data associated with a given sample segment. This includes the sample segment imagery per se coming from the extraction/correction subsystem and archival data and digital support data accessible to the master scheduler. Data is accumulated ahead of time and transferred via the second set of disc controllers to the terminal subsystem, on an as needed basis. The intent is to always keep the terminals busy.

Part of the subsystem scheduling function is to insure that a uniform load is supplied to the terminals. If for some reason a terminal falls behind, the disc packs may be removed from the segment data base and temporarily stored for playback later when the terminals are less busy. The first cut at a crop imaging schedule, that is, identification to the Data Input Subsystem (DIS) of specific images which should be supplied to the agricultural system, can be predicted on geographical and biological bases and thus represents part of the system initialization data discussed previously.

Opinions differ, even within the USDA community, as to the scheduling requirements for crop analysis. Some feel that one take (observation) per biophase (unique condition in the phenological development of the crop) is sufficient. Others claim that the crop should be examined at every available (or possible) time that an image can be acquired. In sizing the system, the biological or biophase basis was taken for the baseline. During the season, gross deviations to this initial schedule can be anticipated. Typical factors requiring rescheduling include:

- inability to acquire the scene: rejection by the DIS on the basis of more than 90% cloud cover
- inability to acquire sample segments; rejection by the agriculture system on the basis of 10% or more cloud cover per sample segment
- image or sample segment retake requested by the agricultural scientist/analyst
- special request for anomaly or episodal event investigation

Schedules for requested imaging will be supplied to the DIS via modem interface or other means depending on the physical location of the agricultural system relative to the location of the DIS.

The Schedule and Control Subsystem is responsible for maintaining image archives. These will be kept on high density digital tape of the same type used for image input to the agriculture system. This will permit the tape recorders to be used interchangeably via a patch or switch box which also provides functional redundancy. A second program decommutator, of the same type used in the extraction/correction subsystem, is employed to acquire data on playback. A data formatter, not shown in the figure, will serialize data from the PDP 11/70 computer and add the necessary synchronization information to permit playback.

Data to be archived will include the following:

- historical meteorological data from NOAA, augmented by the agricultural system
- historical acreage yield and production data from external sources or resulting from systems analysis, corrected if possible, on the basis of aposteriori information
- sample segment image data for the previous season and the current season. Previous season imagery will typically be used to select tentative training sites at the start of the new season and for comparison with current results. Imagery from previous biophases of the current season can be used to adjudge the accuracy of current estimates and for temporal analysis.

The Schedule and Control Subsystem includes a boundary digitizer for inputting line drawings, such as partition boundaries, meteorological isolines, map information, and training site field boundaries. A plotter will permit line drawings to be output on acetate for functions such as map overlays of classified data, theme boundaries, and historical episodal event information, such as the spread of a crop infestation.

The subsystem also includes a color film recorder, of the Optronics or Dicomed variety. Its principal use would be to prepare hard copy color prints at the request of the agricultural scientists/analysts of raw or processed image data. A 70mm format has been assumed which would yield high quality sample segment imagery and/or somewhat reduced resolution full scenes. It was felt that the infrequent requirement for high resolution full imagery, which is always available from the Product Generation

and Dissemination Facility on order, did not warrant the much higher expense of a laser recorder. Since film recording is not an inline system requirement, a minimum cost low thruput rate chemical processing capability is included in the baseline.

3.1.3 STATION TERMINAL SUBSYSTEM

The baseline agriculture system includes 16 station terminals to handle the full data load of 318 scenes per day. These are identical to each other and are employed for crop area and yield estimation purposes. One such terminal is shown in Figure 3-5. This is a combination of hardware and functional units. The spectral and spatial processor units are hardware associated but represent capabilities which are not currently available commercially as shown. These terminal stations are the primary agricultural scientists/analysts interface with the system. The analyst will conduct and supervise the interactive classification process through these terminals.

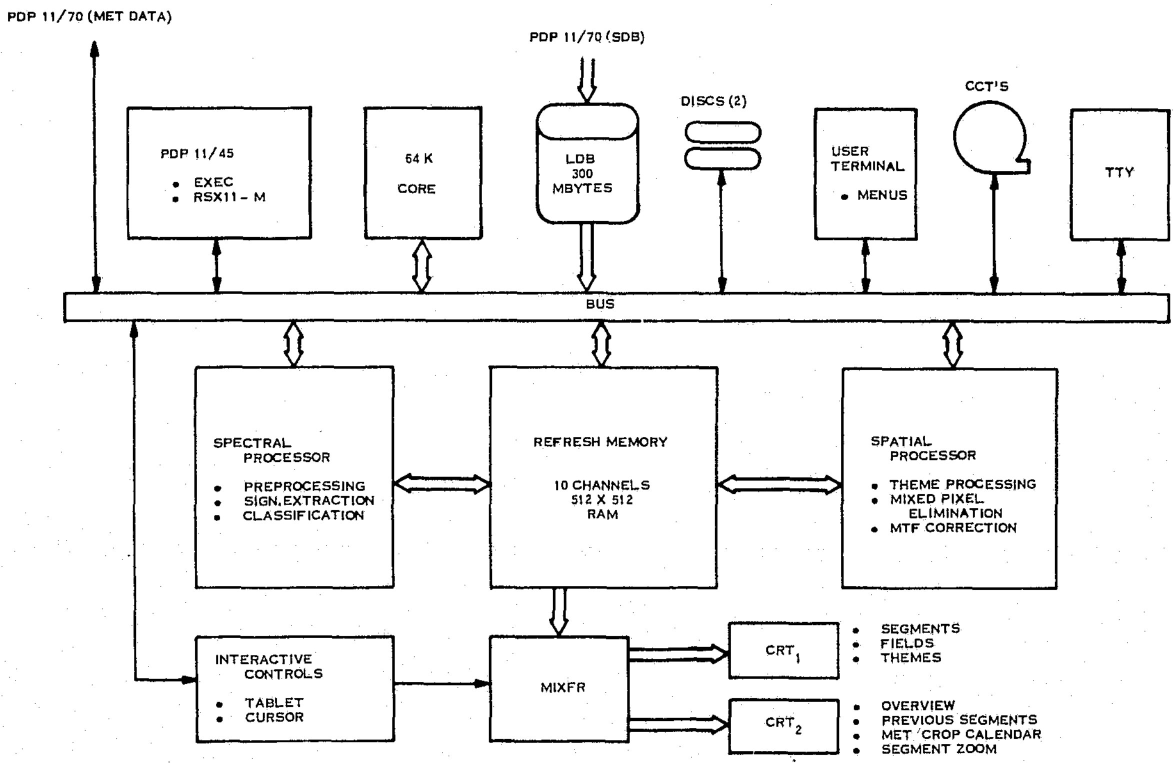

Figure 3-5. Area Estimation Terminal Architecture

The terminals are scoped for two-shift-per-day, 5-day-per-week operation. The baseline concept is to assign terminal responsibility by nation or geographic region. For example, large nations such as the US or Russia, could have one or more terminals assigned to them. Other terminals would be assigned by geographical region. For example, one terminal to handle several European nations or one terminal to handle South America. This organization requires that one terminal handle several or perhaps all of the crops being inventoried. Some differentiation of crops could be handled on a shift basis, but some mixing is still mandatory. This represents somewhat of a departure from current thinking insofar as it requires that agricultural experts be trained in more than one crop area of expertise. This crossing of crop lines is mandatory if the system staffing is to be kept within reasonable limits. Note that all terminals are owned and operated by the USDA and will most likely be colocated at a single USDA installation.

Each terminal has its own computer, a PDP 11/45 or equivalent. The line up of peripherals include:

- 64K words of core
- one 300 Megabyte disc unit; the disc interfaces with the 11/70 to permit loading of accumulated sample segment information from the segment data base archives. Typically the disc would store information for 70-100 sample segments, a mix of data awaiting processing by the terminal and processed data awaiting transfer to the scheduler controller subsystem archive.
- Two RKO5-type discs for storage of terminal software and the local data base. The local data base would be associated with processing for the assigned region/nation and crops, for example, regression models for yield estimation, regional meteorological data, segment training site boundaries and various types of supportive data.
- One or more computer compatible tape units for supplemental or local data base storage and access.
- A teletype unit or external interface with user and data source (external) interfaces
- An alphanumeric user terminal for computer/software access and control
- Computer-to-computer interface with the PDP 11/70 schedule control subsystem computer.

Special purpose equipment is associated with the standard terminals as shown in Figure 3-5 (above). A 10-channel random access memory type refresh memory is

indicated. One of the functions of the refresh memory is to drive two CRT color displays. Application of these color CRT's is varied. For example, one of them could display an overview of the image to be processed while the second one is examining a sample segment in greater detail. This, for example, could be used during the initial phases of the season to identify training sites. Alternatively the two CRT's could be used to display two successive biophase sample segment images.

Location of the sample segment in the 512 x 512 field would be defined by a cursor. Translation capability exists for moving one image or theme relative to another for visual temporal comparison of data. Interactive controls on the display could include a tablet or cursor. The tablet, of the type used in automated drafting systems, would permit manually inserted lines to be translated into imagery; for example, the introduction of modifications to partitions or the meteorological isolines to be introduced by hand. Rectangular and/or polygonal cursors can be superimposed on the image to identify areas for training and/or classification.

The two blocks labeled spectral processor and spatial processor (it is feasible to combine these two blocks into a single programmable function generator) interface with both the refresh memory and the computer data bus. The refresh memory interface enables interactive processing of displayed information to be carried out under the supervision of the system operator. The computer bus interface enables the spectral and spatial processing functions to be employed in a background mode under software control concurrent with the interactive examination of display data and permits many functions to be performed in essentially an automatic unsupervised mode.

Here we are dealing with area estimating functions; that is, the determination and classification of crops in terms of area under cultivation. Referring to Figure 3-6, typical functions performed in the combination of hardware and software, which comprise the terminal station, are displayed functionally. It is difficult to define a single processing scenario which would utilize all of the employed capabilities, but, in general, processing could process as follows:

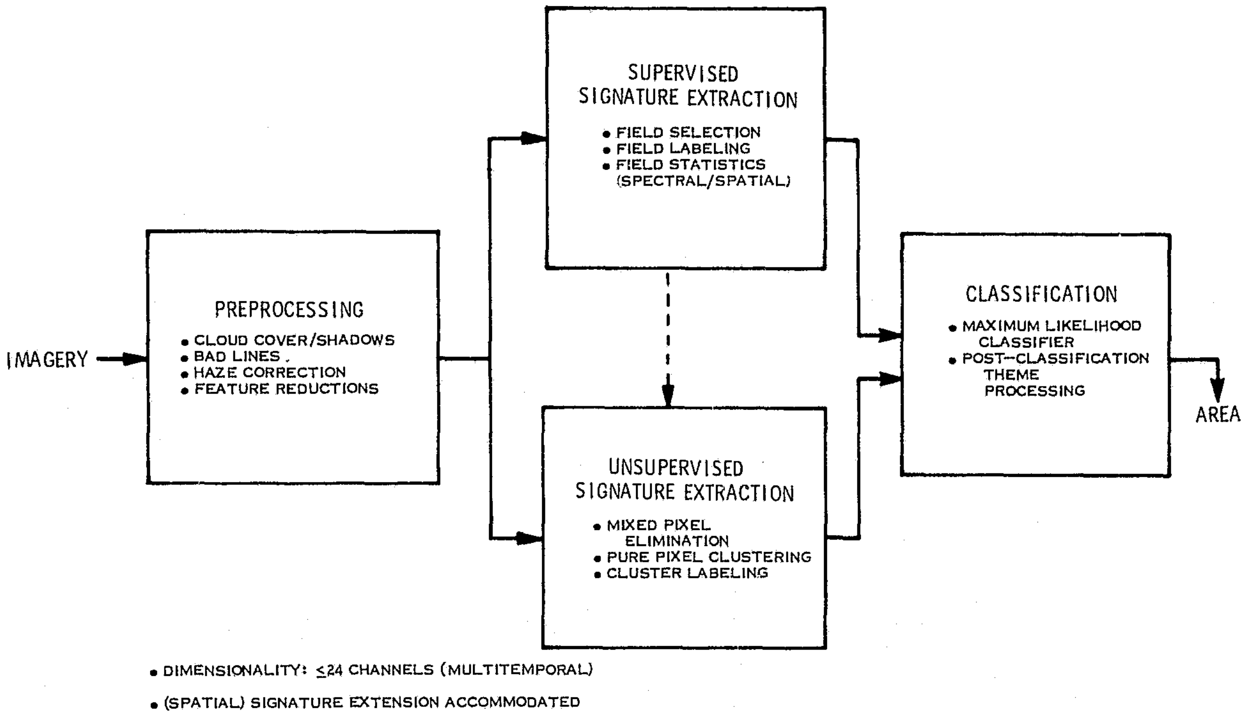

Figure 3-6. Area Estimation Functional Flow

Preprocessing. Input imagery could be automatically examined for cloud cover or shadows present in various areas of interest in the sample segment, that is, in areas defined by the training site boundaries and fields identified from previous analyses. The percent cloud cover would be determined spectrally in the same way that it was in the Data Input Subsystem (DIS) during the 90% filter analyses. Unacceptable data (e.g. bad lines) could conceivably be identified automatically and an established procedure for haze correction or image enhancement, can be implemented. Feature reduction such as the combination of spectral channels in accordance with apriori established criteria can be implemented.

All of these preprocessing functions can theoretically be done automatically without operator attention. In this, as in all cases where autoprocessing is done, the operator will be informed of the results and the processed data retained in memory, keyed for final examination and disposition by the operator before rejection of the data or further processing and inclusion in the area estimation data base.

Supervised Signature Extraction. This is performed interactively under the operators supervision and control and normally involves the services of an agricultural expert. It would involve the identification of fields as training sites, the labeling of these fields as to crop and biophase status, and the gathering of field statistics, both spatial and spectral. The equipment/software will be capable of covariance matrix analysis, that is multi-variate normal distribution processing based on Gaussian statistics. This is almost universally recognized as the most accurate method for identifying signatures. However, the terminal should also be capable of performing non-parametric type analyses (e.g. Image 100 type).

Unsupervised Signature Extraction. The terminal should also be capable of signature extraction in a non-interactive or automatic mode. Functions would include identification of previously defined training sites. It would employ one or more of the parametric or nonparametric analytical techniques to eliminate mixed pixels, to do clustering or spectral partitioning to isolate pure pixels, label the signatures (clusters), and perform statistical analyses; for example, to compare cluster statistics with previous statistics gathered over the same training sites. Since results of previous processing are available in the associated data, the dimensionality problem can be extended; for example, with 4 biophases of 6 channel data, this extension can be to 24 channels in a multi-temporal sense. This, of course, implies that the registration of sample segments is sufficiently accurate to permit pixel comparison, or that the dimensional extension be based on field statistics rather than pixel statistics. Similarly, if acceptable procedures and algorithms are available, signature extension can be accommodated within sample segments and even between sample segments in the same image.

Classification. Classification can be done either interactively or automatically. Bayesian decision criteria such as maximum likelihood will normally be used in classification. The system should also be able to accommodate non-parametric classification techniques (e.g. Image 100). The resulting themes can be spatially modified by various techniques (e.g. application of Golay surrounds). The effect of spatial processing is "to cleanup" the classification theme and can, in fact,

effect an improvement in classification accuracy. Briefly, what it does is modify the classification results based on spatial criteria. That is, if a pixel in the middle of a wheat field is classified as non-wheat than spatial considerations would say that it is wheat and the spatial processor would classify it as such. Typical post-classification spatial operations thus include filling interior holes, eliminating isolated points, smoothing contours, expanding or shrinking contours and edge-tracing, that is, defining boundaries of themes for boundary plot types of outputs.

Spectral/Spatial Processor, Special Purpose Logic. A programmable linear array (vector) processor was taken as the baseline for spectral analysis. This was selected over the two-dimensional array processor on the basis of cost, complexity, and speed. For example, it is estimated that as many as sixteen programmable processors would still cost less than one of the Staran-array type processors. The surveyed processors also provide system redundancy, that is, a single failure will not knock out the entire system. They are also compatible with the phased system development concept, that is, a gradual guild-up to the full system starting with a few terminals and building a full capability based on experience and demonstrated value. Continuing investigation of the vector type programmable processor has tended to verify its selection and to demonstrate that a six-channel processor can implement any of the established techniques for spectral analyses including Gaussian analysis, cluster analysis, Delta classification, etc. Investigation results also favor merging spectral and spatial processing functions into a single programmable unit.

3.2 HYDROLOGIC LAND USE

The hydrologic land use processing center will be a flexible analysis and processing facility. Its main components will include an interactive processing terminal, a central computer data base, and a number of versatile input/output devices. The implementation of these systems is shown in Figure 3.7.

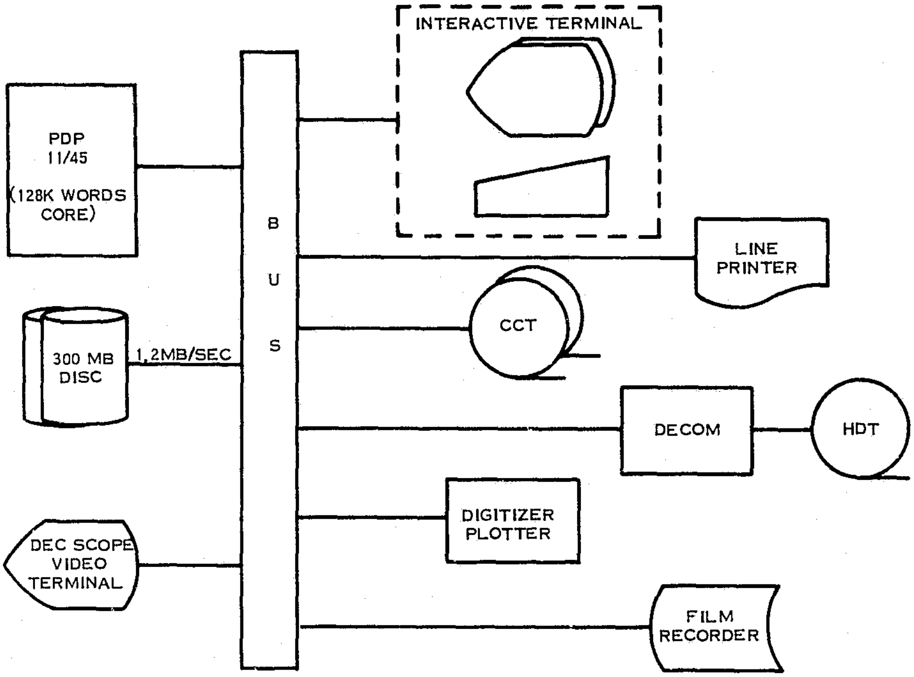

Figure 3-7. System Implementation

The low system throughput rate of 1774 frames per year allows for a one bus design which is cost effective in a number of areas. First, the interactive processor will be of the same general design and contain many common software elements as the interactive processor (terminal station) in the agricultural mission. It is estimated that with this system design, the hydrological land use processing center is operating at about 20% of its peak capacity. This allows for a large increase in processing volume before additional components would have to be added to the system. When the projected demand exceeds the capacity of this system, an additional interactive terminal may be tied into the system, allowing for modular system growth.

3.2.1 THE INTERACTIVE TERMINAL

The interactive terminal is basically the same as that used in the agricultural mission. During the design of the hydrologic land use system, it was determined that based on the volume anticipated, a PDP 11/35 would be sufficient to accomodate the system requirements. However, since the interactive processor for the agricultural mission was designed with a PDP 11/45, it was decided that taking advantage of the hardware and software developed on the agriculture system would be cost effective and thus an 11/45 was used for this mission.

3.2.2 SOFTWARE

The software requirements of the hydrologic land use system will be discussed in terms of those which are not already contained in the software required for the agricultural mission. Those software elements that are common with the agricultural mission will be assumed to be available, at no cost. The differences in software requirements are due to different operating requirements in three areas: (1) cloud cover assessment, (2) larger scene subset areas to be processed, and (3) different requirements for the data base manager.

In the agricultural mission, if the cloud cover of a particular segment exceeds a threshold, the segment is discarded. Otherwise the cloud cover is ignored and will be accounted for during classification. Since the hydrologic land use system will be processing larger scene subsets (complete scenes on occasion) it will be necessary to strip out cloud covered areas.

Since larger scene subsets will be processed, the software controlling several of the output devices, such as the line printer, plotter, and film recorder will also have to be modified.

The requirements for the data base manager will be different than for the agricultural system, due to the variety of data which must be stored. Such files as the standard order processing file, coordinate data for large areas, and the supplementary data such as soil maps, slope contours, erosion indices, etc. will place additional operating requirements on the data base manager.

3.2.3 PERIPHERAL DEVICES

A number of standard, "off-the-shelf" peripheral devices will be employed in the Hydrologic Land Use processing system. Each of these has shown to be compatible with the PDP 11/45, incorporated in the design.

The 300 Mbyte disks and disk controllers are available from DIBA and employ an Ampex disc drive. The disc pac allows for the capability of storing an entire Thematic Mapper scene on one disk. In addition, disk cartridges, similar to the IBM 3330, are available for less than $1,000.

The DEC Scope Video Terminal used is simply an alphanumeric I/O device. A hard copy output option was not included as it was considered unnecessary. The line printer is a standard slow-speed DEC printer.

The computer compatible tape drives and the high density tape drivers are similar to those used in the agricultural system and in the Product Generation and Dissemination Facility. Besides being used to produce products, the CCT recorders will be used for system recovery. The Serial Interface Unit required to decommutate the high density tape data is a "one direction" device. That is, high density tapes will be read but not written on.

The digitizer/plotter and the film recorder are again similar to those used in the agricultural system. The Faul-Coradi Auto-Coradograph is available with a direct interface to the PDP 11/45.

SECTION 4

ALTERNATE SYSTEM DESIGN

As part of this User Data Processing Study it was decided to investigate the size and scope of an alternate user data processing configuration. The mission selected for this induced mission analysis was the Agriculture mission. For this key Landsat D user, an alternate set (reduced in scope) of mission requirements were formatted and the system design was modified to correspond with those reduced requirements. Estimates were then made of the recurring and non-recurring costs of this reduced system.

Inherent in the definition of the reduced mission requirements was the desire to provide for growth capability such that, over time, the requirements could increase and the system could "grow" up to the full capability baseline definition. The basic change made in the definition of the mission was a reduction in scope from a full global inventory of 6 crops to a basic capability for wheat only plus minor capability for other crops.

This definition of the mission requirement was interpreted as corresponding to an initial system loading of 50 to 100 scenes per day with growth potential to the baseline capability of 318 scenes per day. This change in the basic capacity as well as other differences between the "baseline" capability and the "minimum" capability are summarized in Table 4-1. These changes are reflected in the equipment configuration by the modifications indicated in Figure 4-1.

When considering this alternate design, and its corresponding costs in the following section, care should be taken that undue significance is not placed on the particulars. The entire purpose was to explore, in a gross sense, the cost sensitivity to changed requirements. The design arrived at, and its cost, is not intended to represent a finely tuned and optimized design for the absolute minimum system.

Table 4-1. Comparison of Minimum and Baseline Agricultural Missions

	BASELINE	MINIMUM
MISSION		
CROP INVENTORY	WORLD-WIDE	WORLD-WIDE
CROPS	WHEAT, CORN, SOYBEANS, POTATOES, RICE, SUGAR, SMALL GRAINS	WHEAT +
EVENTS/CONDITIONS	EPISODAL, ANOMALY	EPISODAL, ANOMALY
PROCESSING CAPABILITY		
SCENES/DAY	320	100
SAMPLE SEGMENTS/DAY	2352	213
INTERACTIVE - PERCENT & TIME	20% - 32.7 MINUTES	60% - 1 HOUR
AUTOMATIC - PERCENT & TIME	80% - 6.6 MINUTES	40% - 1.5 HOURS
EQUIPMENT		
HDT'S	4	2
PROGRAM DECOMMUTATORS	2	1
GEOMETRIC CORRECTION	HARDWARE	SOFTWARE
CORRECTION COMPUTER	1 - PDP 11/45	2 - PDP 11/45
DISK DRIVES/CONTROLLERS	4/6	2/3
TERMINALS	16	8

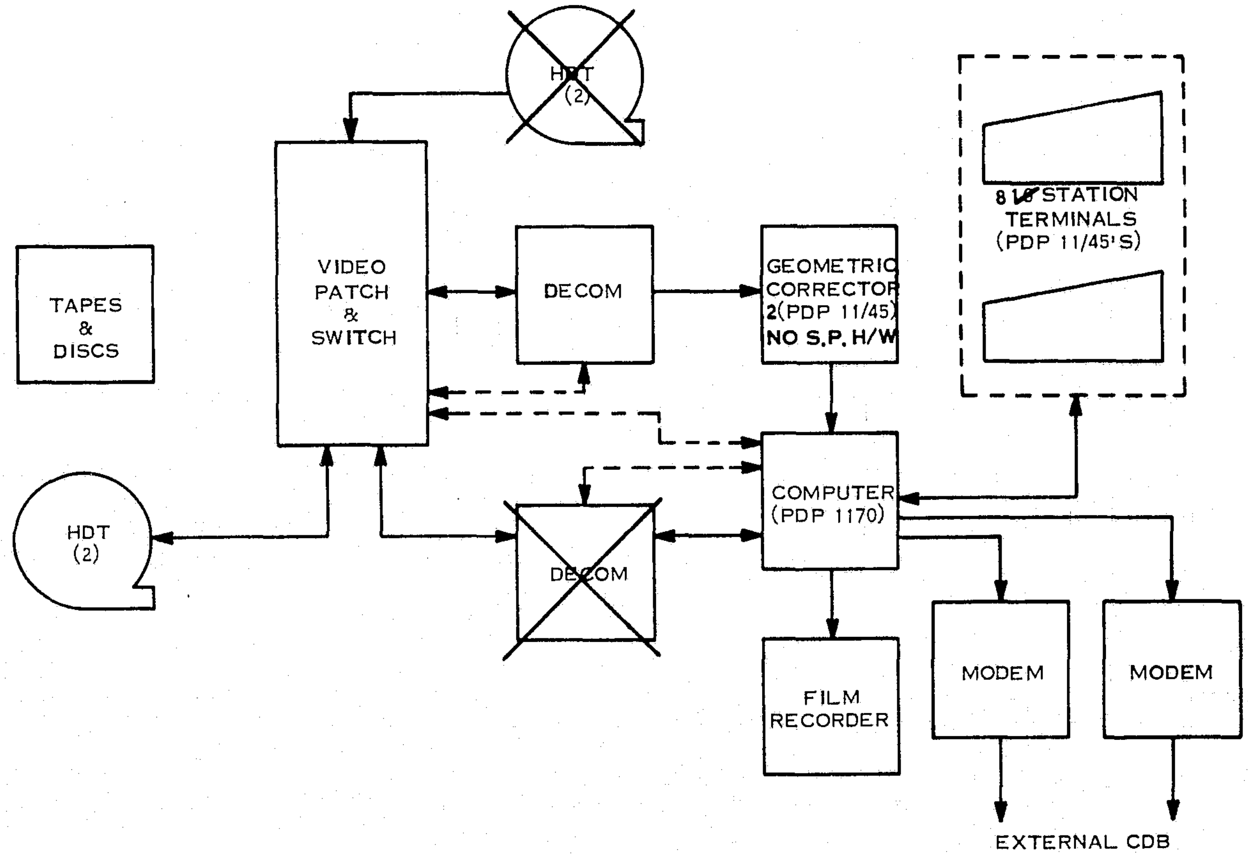

Figure 4-1. Minimum Agricultural Mission Equipment Configuration

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SECTION 5

COST ESTIMATES

As part of this study it was required to provide Rough-Order-of-Magnitude (ROM) cost estimates of the recurring and non-recurring costs of these User Data Processing systems. The purpose of these (non-NASA) cost estimates is their intended use in developing a total (spacecraft and ground - NASA and non-NASA) cost/benefit economic analysis.

Econometric models have been developed which provide estimates of the economic benefit expected to accrue to the United States from the implementation of various remote sensing based application missions. In most cases these benefits are based on an increased or new mission capability which is provided or enabled through the use of remote sensing. The benefits associated with this incremental increase (over the existing or alternative mission) in mission capability must of course be compared with the incremental costs necessary to achieve the improved capability.

For the agriculture and hydrology missions described in this study the increased mission capability is derived from the analysis of Landsat D data incorporated with other information sources. The user costs associated with processing that data and extracting the useful information, up to the point where it can be assimilated into the existing system, are addressed in this section.

The other explicit missions addressed in this study, Forestry and Mineral Exploration, are not costed here because of the derivation of their economic benefits. For these missions the economic benefits are already estimated on a net basis. That is, the econometric models already account for the incremental cost associated with the user processing of Landsat D data. Since these costs are already included in the economic cost/benefit models no attempt was made in this study to define them explicitly. For the economic benefits, it is sufficient that the Landsat D data be made available to these users; this is provided by the centralized NASA Product Generation and Dissemination Facility (PGDP).

Although every effort was made to make these cost estimates as accurate as possible, it must be remembered that these are only ROM estimates to be used for budgetary and planning purposes. The cost estimates are, of course, directly related to the system requirements and resulting design upon which they are based. As the mission becomes better understood, and the requirements more definitive, it is expected that the costs will change from these initial estimates.

5.1 COST ESTIMATING GROUNDRULES AND ASSUMPTIONS

The following groundrules and assumptions were adopted during this study for purposes of arriving at the cost estimates. They are an integral part of the resulting ROM estimates and should be reviewed closely.

1. An average labor rate of $48K per year through overhead and G&A (and before fee and contingency) was used for each applied man throughout the design, fabrication, and test phases of the program. This value represents a reasonable mean between the higher paid senior engineers/managers and the lesser paid technicians/shop personnel.

2. Field rates were used for estimating the cost of training operators and for the recurring station operations. These rates were supplied by NASA/GSFC and are as follows through overhead and G&A per year.

   - Managers/Engineers/Supervisors - $36.36K
   - Lead Technicians/Operators - $23.64K
   - Clerical and Support - $13.64K

3. Overhead, IR&D, and General and Administrative rates are included as appropriate in each of the above man-year labor rate categories (direct and field support). The inclusion of these makes the labor rates used fully burdened and thus they only require the final addition of a contingency factor and profit (or fee).

4. Costs were included for contract support and similar support activity, in addition to the basic catalog price for all purchased items.

5. All costs provided are in basic 1976 dollars; no forward pricing or inflation factors were used in these estimates.

6. Where newly designed items are used in more than one subsystem of the Landsat D ground system, the engineering design and drafting costs (non-recurring) were only costed once.

7. Published catalog prices were used for estimating purchased hardware and software whenever possible; in a few cases it was necessary to rely on engineering estimates and past experience for estimates of these purchased items.

8. The cost estimates presume the use of a private (for profit) contractor for all items and include provision for fee or profit at the rate of 10% on total cost.

9. No provision in the cost estimates is made for the physical facilities, land, security, nor operational utilities (light, power, heat, etc.); all of these are assumed to be provided by the government at no explicit cost to the project.

10. A contingency factor of 10% is included in the final total cost to account for some flexibility in requirements growth and unanticipated cost items.

11. No provision was included in the cost estimate for a warranty or guarantee beyond system acceptance. Any warranty or service contract of this type would be additional.

5.2 COST BREAKDOWN STRUCTURE

The cost estimates for the user data processing facilities were derived from a "bottoms-up" analysis of each cost element. A cost breakdown structure was developed to four levels of depth as shown in Figure 5-1. Included on this figure are the major task elements which constitute the cost elements. The following descriptions summarize the third level of the cost breakdown structure.

1. System Engineering - this element provides for the overall design definition and integration of the various subsystem elements. Design reviews are provided for and the performance requirements are established.

2. Equipment Design and Fabrication - this element accumulates the cost of equipment design and manufacture. Purchase of material and bought components; the detailed electrical, mechanical, and packaging design; the necessary drafting and analysis support; and special test equipment design are all included in this cost element.

3. Software Design and Test - because of the importance of software as a key element in digital systems it has been given particular visibility. Included are both the software design and software test activities.

4. System Integration and Test - provides for the subsystem and system level tests of the integrated components. This is representative of the final test at the contrac-tractors facility prior to the shipping of equipment to the installation site.

5. Site Installation and Checkout - includes the actual shipment of equipment to the operational site as well as the performance of the final acceptance test on the system.

6. Personnel Training - a training course will be conducted to train the on-site field personnel who will operate and maintain the system.

7. Program Management - provides for the overall management and control of the entire systems development activity. Program management, administrative, and clerical support are included as well as providing for reports and communication with the customer.

8. Station Operations - this cost element provides for the yearly recurring costs which begin following the final acceptance test. The principal cost here is that of the on-site field personnel responsible for operating and maintaining the system. Costs are also included for expendable and consumable material items as well as for replacement spare parts.

5.3 COST ESTIMATING PROCEDURE

A "bottoms-up" cost estimating approach was used to estimate each of the various cost elements in the cost breakdown structure. In all cases the initial engineering and manufacturing cost estimates were reviewed by three levels of management to ensure their accuracy and consistency with recent experience. The following paragraphs are intended to provide some understanding of the rules-of-thumb applied and the procedures followed.

For each of the subsystems, a parts list was developed with each part identified and costed. A percentage was added to the catalog price of purchased items for the contract support required to generate the documentation and provide the necessary controls to purchase all buy items. The cost of the materials required for the newly designed items was estimated based on experience with similar items developed for previous ground stations. The labor effort required to design and manufacture the make items, and to provide the necessary design and manufacturing effort to develop the source control drawings, procurement specifications, and to assemble the buy items, were also estimated based on experience gained with similar equipment.

Catalog prices were used for all purchased items. The labor effort required for the design, drafting, and manufacturing of new items was based on experience with similar equipment, with appropriate complexity factors to adjust the total cost. Material costs were based on the number of electronic circuit boards, the number of parts per board, etc. The systems engineering task was costed based on a level of effort across the two (2) year assumed program duration.

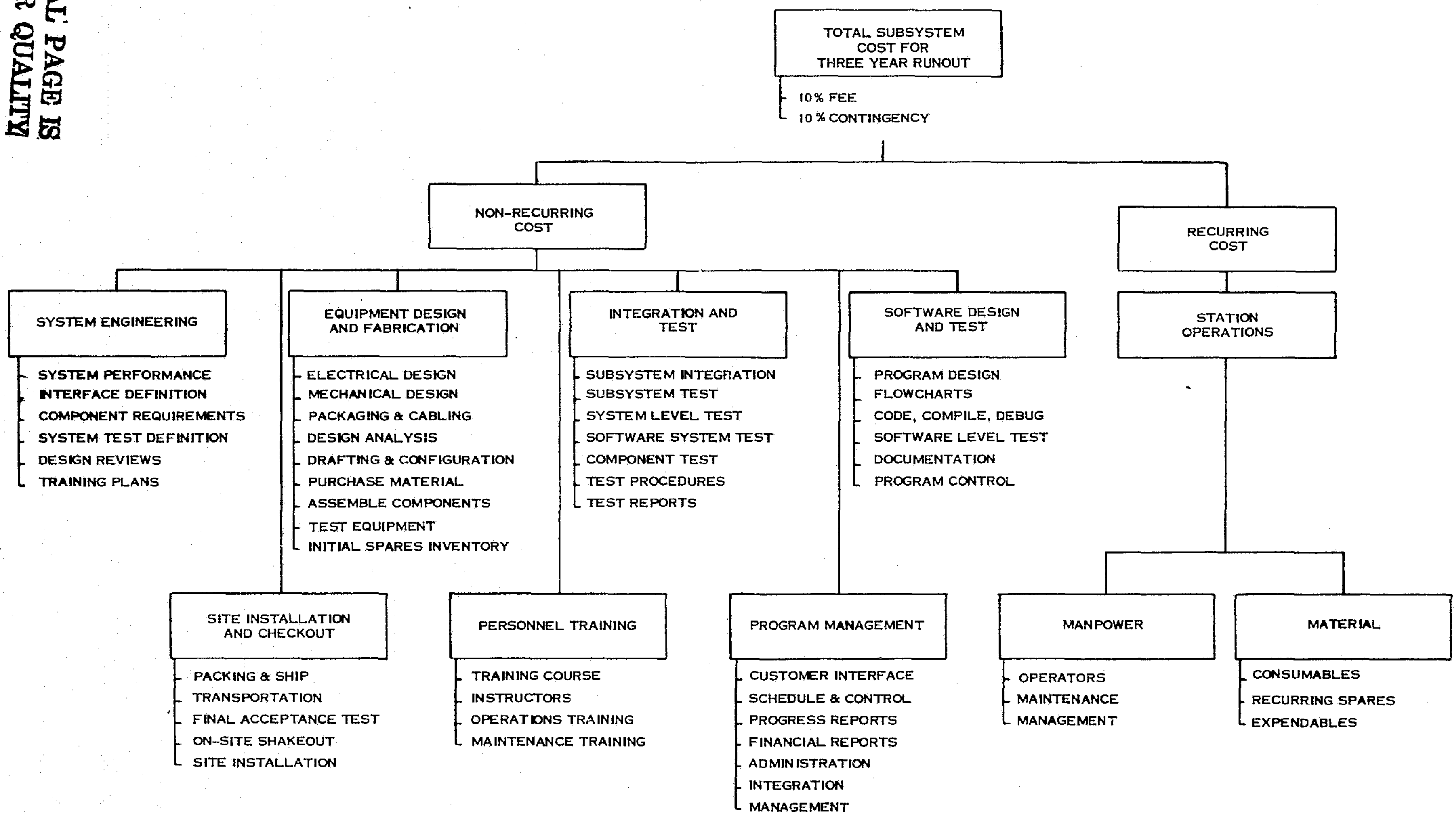


Figure 5-1. Cost Breakdown Structure

Ten (10) percent of the total material dollars were added to account for non-recurring spares. No specific analysis was conducted as to the detailed repair and replacement level nor were particular equipments identified for sparing. Rather, the 10% rule-of-thumb was applied across the board.

Catalog prices were used for all purchased software packages. The labor required to design the operational and test software, and to perform the debug and verification, was based on experience with similar software systems developed on previous programs and adjusted according to their relative complexities.

The System Integration and Test task was costed by estimating the number of people required to conduct and operate the particular subsystem equipment over the integration and test period.

The cost to pack and ship each subsystem was based on the number of equivalent single bay racks weighing approximately 800 pounds each. Each rack would be supported on a skid (100 pounds each) and the cost for shipping is approximately $20 per 100 pounds. The installation and acceptance test efforts were costed based on the estimated number of men required over the given installation and test periods.

This task was costed by estimating the number of operators to be trained along with their associated labor category. Field rates were used for all site personnel and the standard contractor rates were used for the instructors. The training time allocated is based on the relative complexity of the subsystem.

The recurring station operations were costed by estimating the number and labor category of the site personnel required, and the number of shifts the station will be in operation. The NASA supplied field rates were used. A yearly recurring expenditure of 1% of the total material dollars was added for non-replaceable spare parts. The level and category of personnel used to estimate these recurring costs are shown in Table 5-1.

Table 5-1. Recurring Manpower Estimates

Labor Category	Agriculture Utilization		Hydrology
	Baseline	Minimum	
Managers	1	1	1
Engineers	16	8	2
Supervisors	-	-	-
Lead Technicians	4	4	2
Operators	68	33	4
Gophers	4	2	2
Clerical & Support	5	4	1
Total	98	52	12

5.4 COST ESTIMATES

For this study, three cost estimates of the user data processing subsystems were developed. These are:

1. Agricultural Utilization Subsystem (Baseline - 318 scenes/day)
2. Agricultural Utilization Subsystem (Minimum - 50-100 scenes/day)
3. Hydrological Land Use Subsystem

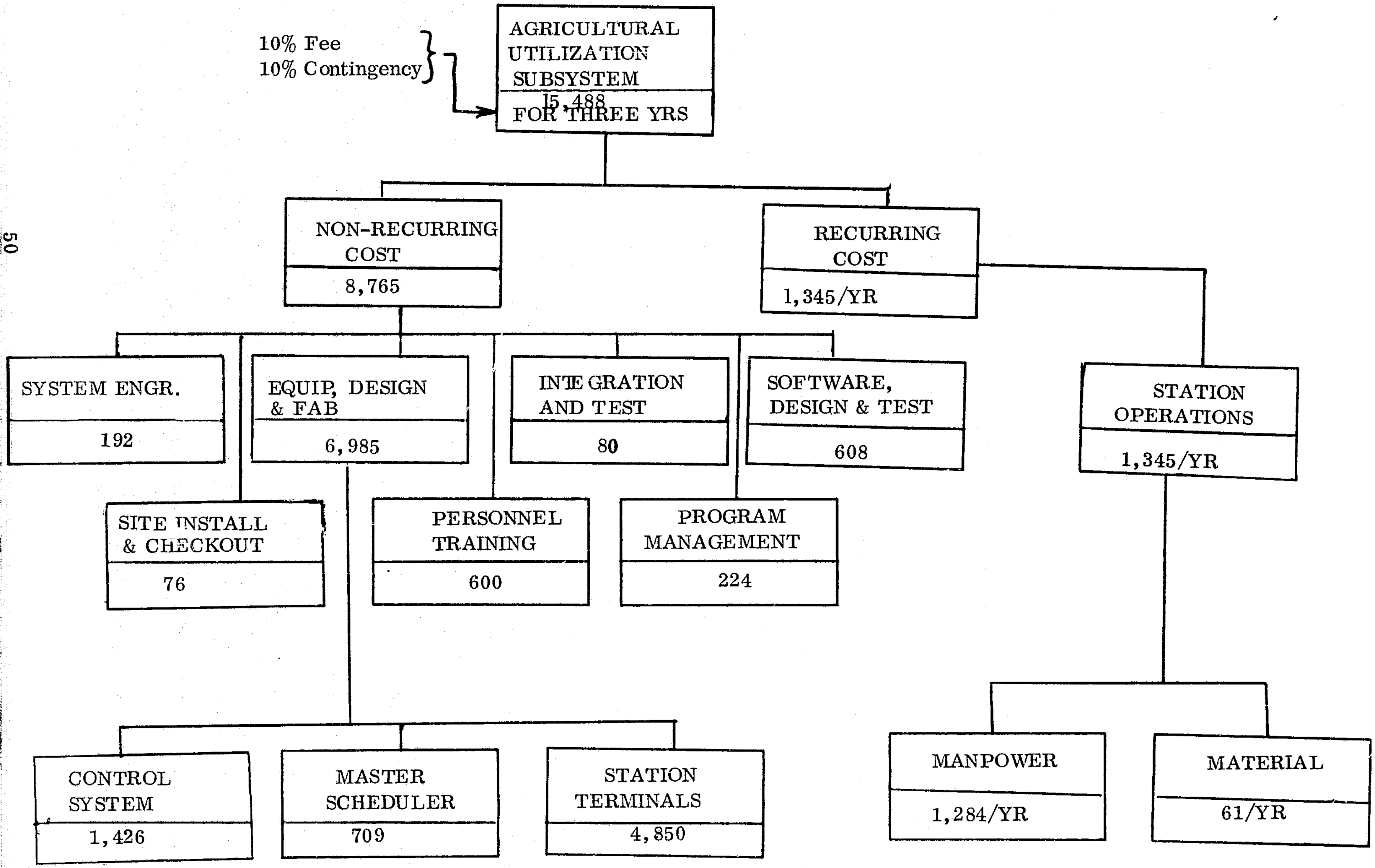
The cost estimates for each of these are summarized in Table 5-2 below. They are shown in their cost breakdown structure format in Figures 5-2 and 5-3 for the (minimum) Agricultural Utilization Subsystem and the Hydrological Land Use Subsystem respectively.

Table 5-2. User Data Processing Cost Summary

Item	Agricultural Mission Minimum	Agricultural Mission Baseline	Hydrological Mission
Non Recurring Costs			
System Engineering	192	768	192
Equipment Design	6,985	12,392	1,628
Software	608	618	244
System Integration	80	120	80
Site Installation	76	112	40
Training	600	1,080	32
Program Management	224	1,044	216
Total Non Recurring	8,765	16,134	2,432
Thru Fee	10,606	19,522	2,943
Recurring Costs			
Manpower	1,284	2,443	292
Material	61	131	156
Total Recurring	1,345	2,574	448
Thru Fee	1,627	3,115	542

1976 dollars x 1000

Thru Fee = use of 10% fee and 10% contingency



1976 DOLLARS X 1000

Figure 5-2. Agricultural Utilization Subsystem (Minimum) Cost Summary

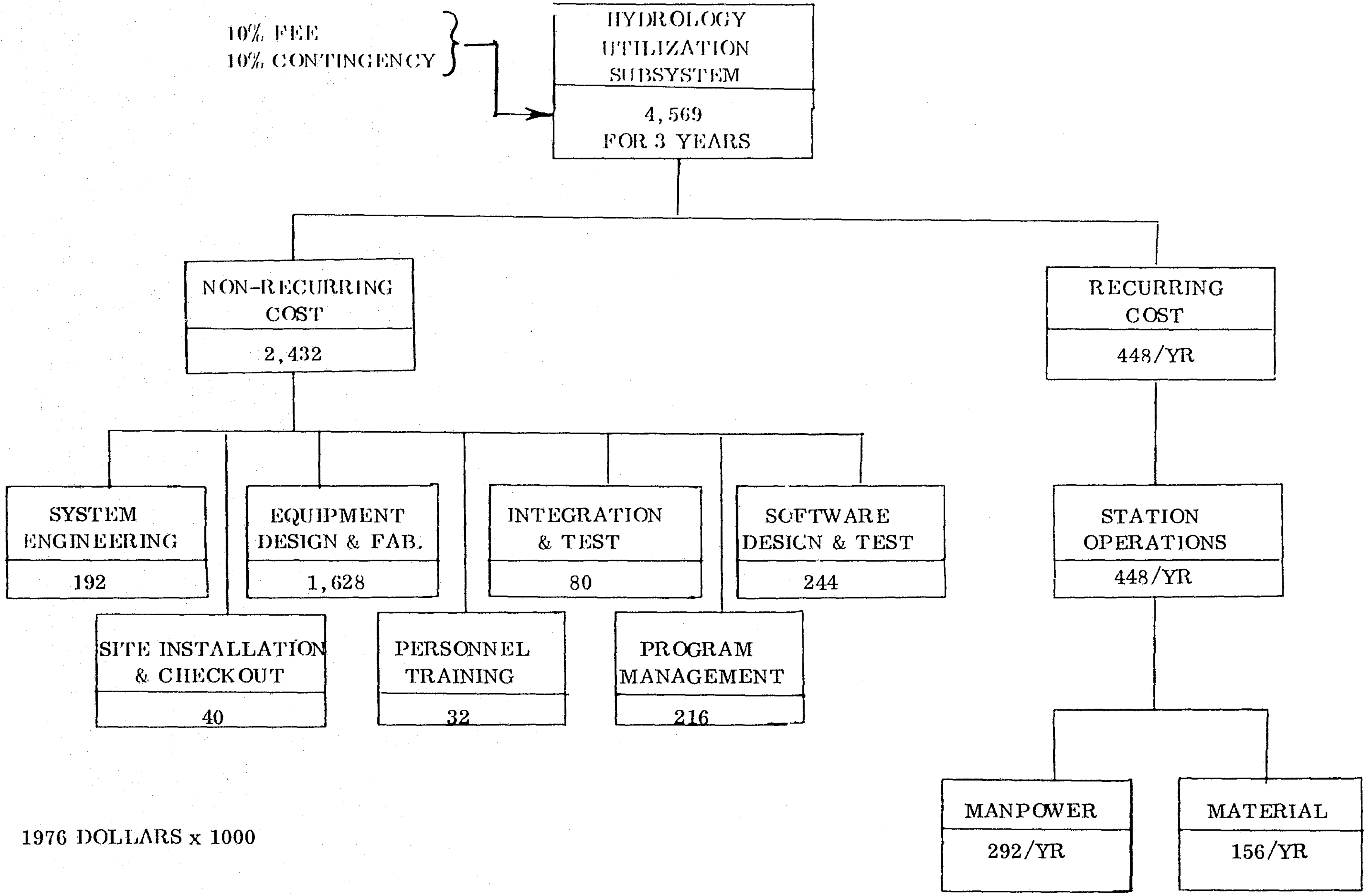


Figure 5-3. Hydrological Land Use Subsystem Cost Summary